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Description

This invention relates to apparatus and methods for analyzing the composition of formation fluids, and more particularly to apparatus and methods for using near infrared spectral analysis to determine the quantities of gas, water and various types of oils in a formation fluid.

As seen in Figure 1, several different interactions may occur when light strikes a sample. Typically, if the sample is fluid, some light is reflected at the boundary of the sample while the rest of the light enters the sample. Inside the sample, light is scattered by molecular excitations (Raman scattering) and by collective modes of the medium (e.g. Rayleigh scattering). In general, only a very small fraction of the light is scattered per centimeter of the path by the Raman and Rayleigh scattering processes.

If more than one phase is present in the sample, light is elastically scattered by reflection and refraction at the boundaries between the phases. This scattering process can be quite strong as light may he scattered many times in less than one centimeter of the path. Light which is not scattered or which is scattered but emerges from the sample travelling in a direction nearly parallel to and in the same direction as the incident light is generally referred to as "transmitted". Light which emerges travelling in other directions is referred to as "scattered", while light which emerges travelling in a direction nearly opposite to the incident fight is referred to as "backscattered".

Regardless of scattering, some light is absorbed by the sample. The fraction of incident light absorbed per unit of pathlength in the sample depends on the composition of the sample and on the wavelength of the light. Thus, the amount of absorption as a function of wavelength, hereinafter referred to as the "absorption spectrum", an indicator of the composition of the sample. In the wavelength range of .3 to 2.5 microns, which is the range of primary interest according to this invention, there are two important absorption mechanisms in borehole fluids. In the near infrared region (1 to 2.5 microns), absorption results primarily from the excitation of overtones of molecular vibrations involving hydrogen ions in the borehole fluids. In the near ultraviolet, visible, and very near infrared regions (covering wavelengths of .3 to 1 micron), absorption results primarily from excitation of electronic transitions in large molecules in the borehole fluids such as asphaltenes, resins, and porphyrins.

In the past, techniques have been known for the qualitative and quantitative analysis of gas, liquid, and solid samples. Methods and apparatus for accomplishing the same are disclosed in U.S. patent no. 4,620,284 to R. P. Schnell where a helium-neon laser is used to provide photons of a .633 micron wave length which are directed at a sample. The resulting Raman spectrum which comprises scattered tight at different wavelengths than the incident light is then measured, and the measured spectrum is compared with previously obtained reference spectra of a plurality of substances. The provided technique is applied to monitoring fluid flowing through a pipeline in an oil refinery.

In U.S. patent no. 4,609,821 to C. F. Summers, especially prepared rock cuttings containing at least oil from an oil-based mud are excited with UV radiation with a .26 micron wave length. Instead of measuring the Raman spectrum as is done in the aforementioned Schnell patent, in accord with the Summers disclosure, the frequency and intensity of the resulting excited waves (fluorescence) which are at a longer wavelength than the incident radiation are detected and measured. By comparing the fluorescent spectral profile of the detected waves with similar profiles of the oil used in the oil-based mud, a determination is made as to whether formation oil is also found in the rock cuttings.

While the Summers and Schnell disclosures may be useful in certain limited areas, it will be appreciated that they suffer from various drawbacks. For example, the use of laser equipment in Schnell severely restricts the environment in which the apparatus may be used, as lasers are not typically suited to harsh temperature and/or pressure situations (e.g. a borehole environment). Also, the use of the Raman spectrum in Schnell imposes the requirement of equipment which can detect with very high resolution the low intensity scattered signals. The use by Summers of light having a .26 micron wavelength severely limits the investigation of the sample to a sample of nominal thickness. In fact, the Summers patent requires that the sample be diluted with solvents before investigation. Thus, the Summers patent, while enabling a determination of whether the mud contains formation oil, does not permit an analysis of formation fluids in situ. Finally, the Summers method has no sensitivity to water.

GB2217838A discloses methods for determining petrophysical and petrochemical properties of material using near infrared spectra. In the methods described, samples of fluids, solids or porous solids (cuttings, core samples, etc.) containing fluids are subjected to analysis. These methods suffer from the disadvantage that it is necessary to transport samples to the surface for analysis with the associated problem of extended time for analysis and the possibility that the samples at the surface are not representative of the sample downhole.

US 4,001,595 discloses the use of multiple wavelengths of radiation for transmission measurements across a single chamber through which a fluid can flow. the object of the method is to obtain particle size distribution of particulates in the flow and/or mass concentration.

Those skilled in the art will appreciate that the ability to conduct an analysis of formation fluids downhole is extremely desirable. A first advantage would be the ability to distinguish between formation fluids and mud filtrate, thereby permitting a fluid extraction tool to retain only fluids of interest for return to the formation surface. A second advantage is in the production phase, where a determination of the fluid type (i.e.. water, oil, or gas) entering the well from the formations can be made immediately downhole.

SUMMARY OF THE INVENTION

It is therefore an object of the invention to provide a method and apparatus for analyzing the composition of a formation fluid which may include water, gas, one or more of a plurality of oils, and solid particles.

It is a further object of the invention to provide a downhole apparatus for analyzing in situ the composition of a formation fluid.

It is another object of the invention to provide an apparatus using at least the near infrared spectrum for analyzing the composition of formation fluid.

In accordance with the present invention, there is provided an apparatus for analyzing the composition of a formation fluid comprising at least one of oil, water and gas, and including a light source for emitting infrared radiation, means for directing the radiation from the light source to a chamber containing the formation fluid to be analyzed, a detector for detecting radiation transmitted through the fluid in the chamber and means for analyzing the composition of the fluid on the basis of the transmitted radiation;
characterized in that:

a) the apparatus comprises borehole apparatus containing the light source, the chamber, the means for directing the radiation from the light source to the chamber and the detector, which can be positioned adjacent the formation from which the fluid is to be obtained;

b) means are provided in said borehole apparatus for admitting fluid from the formation into the chamber; and

c) the means for analyzing the fluid includes means for obtaining the spectrum of the light source and processing means including a database of near infrared absorption spectral information of at least two of oil, water and gas, said processing means determining the composition of the fluid using the transmitted spectra, the light source spectrum and the data in the database.

The chamber may, for example, comprise either a tube through which the formation fluids can flow, a chamber in which the fluid may be kept for transfer to the formation surface, or may comprise a path which interrupts light traveling through a light transmitting means. If a tube or chamber is used, the tube or chamber should include a window which is optically transparent to at least near infrared light, and preferably also to near ultraviolet and visible light. The light source may be an incandescent lamp with a known or determinable spectrum, and the emitted light is directed at least partly towards the window in the tube or chamber either via collimation or fiber optics. The spectral detector means is preferably a spectrometer which detects and measures the spectrum of the light which has been transmitted through the fluid sample. Typically, the spectrum detector means also includes directing and focusing mirrors or additional fiber optic bundles.

According to the present invention, there is also provided a method for analyzing the composition of a formation fluid comprising at least one of oil, water and gas, and including the steps of illuminating a sample of the fluid in a chamber with a light source for emitting near infrared radiation, detecting the spectrum of radiation transmitted through the fluid in the chamber and analyzing the composition of the fluid on the basis of the transmitted radiation; characterized in that:

a) the steps of illuminating the sample and detecting radiation transmitted therethrough are performed in a borehole apparatus containing the light source, the chamber, means for directing the radiation from the light source to the chamber and a detector, the borehole apparatus being positioned adjacent the formation from which the fluid is to be obtained;

b) fluid is admitted from the formation into the chamber via means provided in said borehole apparatus; and

c) the step of analyzing the fluid includes obtaining the spectrum of the light source and determining the composition of the fluid with processing means using the transmitted spectra, the light source spectrum and the data from a database of near infrared absorption spectral information of at least two of oil, water and gas, in the processing means.

Knowing the spectrum of the emitted light and the spectrum of the detected light which has been affected by the fluid sample, a determination of the composition of the fluid sample may be had if a data base of the spectra of the possible compo-

nents of the fluid is available. Towards that end, the spectra of water, gas, and a plurality of different oils are found and stored in a data base. Then, using a fitting technique such as a least squares analysis or a principal component analysis, a processing means (e.g. a computer or microprocessor) with access to all the information can conduct the desired fluid component analysis. Preferably, in further accordance with the principles of the invention, spectra of the oils, gas, and water at different pressures and temperatures can be maintained and used in the fitting process. Also, with regards to another aspect of the invention, a determination of a transition of the obtained fluid samples from mud filtrate to formation fluids is made by monitoring the visible light and/or near ultraviolet spectrum for changes in the same.

A better understanding of the invention, and additional advantages and objects of the invention will become apparent to those skilled in the art upon reference to the detailed description of the accompanying drawings.

Figure 1 is a diagram of some of the different interactions which may occur when light strikes a sample;

Figure 2 is a schematic diagram of a first embodiment of a borehole apparatus for analyzing the composition of a formation fluid;

Figure 3 is a schematic diagram of the preferred near infrared fluid analysis module of Figure 2;

Figure 4 is a schematic diagram of the preferred spectrometer of the invention;

Figures 5a - 5c show logarithmic plots of the near infrared absorption spectra of water, crude oil, and kerosene;

Figure 6 is a schematic diagram of an alternative near infrared fluid analysis module of Figure 2;

Figure 7 is a schematic diagram of the fluid analysis module of the invention which is used in conjunction with a production logging tool;

Figure 8 is a schematic diagram of one embodiment of the optic cell in Figure 3, illustrating the use of diffusers;

Figure 8a is a diagram illustrating the effect a diffuser in Figure 8 has on a light ray; and

Figure 9 is a schematic diagram of another embodiment of the optic cell in Figure 3, illustrating the use of mis-alignment.

The instant invention is particularly applicable to both production logging and to borehole investigative logging. For purposes of brevity, however, the description herein will be primarily directed to borehole investigative logging. Thus, a borehole logging tool 10 for testing earth formations and analyzing the composition of fluids from the formation 14 in accord with invention is seen in Figure 2. As illustrated, the tool 10 is suspended in the borehole 12 from the lower end of a typical multiconductor cable 15 that is spooled in the usual fashion on a suitable winch (not shown) on the formation surface. On the surface, the cable 15 is electrically connected to an electrical control system 18. The tool 10 includes an elongated body 19 which encloses the downhole portion of the tool control system 16. The elongated body 19 also carries a selectively extendible fluid admitting assembly 20 and a selectively extendible tool anchoring member 21 which is respectively arranged on opposite sides of the body. The fluid admitting assembly 20 is equipped for selectively sealing off or isolating selected portions of the wall of borehole 12 such that pressure or fluid communication with the adjacent earth formation is established. Also included with tool 10 are a fluid analysis module 25 through which the obtained fluid flows. The fluid may thereafter be expelled through a port (not shown) or it may be sent to one or more fluid collecting chambers 22 and 23 which may receive and retain the fluids obtained from the formation. Control of the fluid admitting assembly, the fluid analysis section, and the flow path to the collecting chambers is maintained by the electrical control systems 16 and 18. Additional details of methods and apparatus for obtaining formation fluid samples may be had by reference to U.S. patent 3,859,851 to Urbanosky and U.S. Patent 3,813,936 and U.S. Patent No. 3,811,321. It should be appreciated, however, that it is not intended that the invention be limited to any particular method or apparatus for obtaining the formation fluids.

Turning to Figure 3, the preferred fluid analysis module 25 is seen in detail and preferably includes a light source 30, a fluid sample tube 32, optical fibers 34, and a spectrograph 36 and associated detector array 38. The light source 30 is preferably an incandescent tungsten-halogen lamp which is kept at near atmospheric pressure. The light source 30 is relatively bright throughout the near infrared wavelength region of 1 to 2.5 microns and down to approximately .5 microns, and has acceptable emissions from .35 to .5 microns. Light rays from the light source 30 are preferably transported from the source to the fluid sample by at least part of a fiber optic bundle 34. The fiber optic bundle 34 is preferably split into various sections. A first small section 34a goes directly from the light source 30 to the spectrograph 36 and is used to sample the light source. A second section 34b is directed into an optical cell 37 through which the sample tube 32 runs and is used for illuminating the fluid sample. A third section 34c originates at the cell 37 and goes directly to the spectrograph 36 and is used to collect light substantially backscattered by the sample. Spectral information obtained by section 34c is helpful in determining the

composition of the sample fluid, and in conjunction with a fourth bundle 34d in determining whether gas is present as will be discussed hereinafter. A fourth bundle 34d collects light transmitted or scattered through the sample and also provides information regarding the nature of the fluid flowing through the sample tube or chamber 32. A three position solenoid (not shown) is used to place one of bundles 34a, 34c and 34d at the input slit (seen in Figure 4) of the spectrograph, and a light chopper (not shown) modulates the signal at 500 Hz to avoid low frequency noise in the detectors.

As aforementioned, optical bundle 34b directs the light towards the fluid sample. The fluid sample is obtained from the formation by the fluid admitting assembly and then is sent to the fluid analysis section 25 in tube 32. In a preferred embodiment, the sample tube 32 is a three by four millimeter rectangular channel. The tube preferably includes a section 40 with windows made of sapphire. This section 40 is located in the optical cell 37 where the light rays are arranged to illuminate the sample. Sapphire is chosen as it is substantially transparent to the spectrum of the preferred light source. Also, sapphire is preferable because it is much harder than silica and resists abrasion. As indicated in Figure 3, the sapphire window areas 40 of tube 32 may be arranged to be thick so as to withstand high internal pressure, and the window areas are offset slightly so that they are kept centered on the path of the transmitted light. The fiber optic bundle 34b is not perpendicular to the flow stream so as to ensure that specular reflection does not enter fiber optic bundle 34c, because specular reflection (reflection due to the interface of the sapphire wall and the liquid sample) does not provide useful information. As a result of the arrangement, optic bundle 34c will receive and conduct substantially backscattered light.

As previously indicated, the fiber optic bundles 34a, 34c and 34d terminate at the spectrograph 36. As seen in detail in Figure 4, the spectrograph includes an entrance slit 52, an off-axis paraboloidal mirror 54, a diffraction grating means 56, and the detector array 38. Light exiting the chosen fiber optic bundle and entering the spectrograph 36 via slit 52 reflects off the off-axis paraboloidal mirror 54 towards a blazed diffraction grating 56. The blazed diffraction grating disperses and diffracts the light into a small range of angles, with rays of different wavelengths being diffracted differently. The diffracted and dispersed light is directed back toward a section of the off-axis paraboloidal mirror which causes the rays of different wavelengths to be reflected and focussed on different elements of the detector array 38. The detector array elements may therefore determine the intensity of the light entering the spectrograph as a function of wavelength. The information may then be multiplexed to a digitizer and prepared for transmission uphole to electronics and processing means 18.

Preferably, the off-axis paraboloidal mirror 54, the diffraction grating 56, and any mounting fixtures (not shown) used to mount them are all made of aluminum so that the thermal expansion of the components will be identical. This arrangement would ensure that the angular relations among the components would not change with temperature. As a result, the position of a given wavelength at the detector plane would be independent of temperature.

With the provided fluid analysis section 25, the spectra of the light source, of the backscattered light which has scattered off the fluid sample, and of the forward scattered and transmitted light may be determined. When the transmitted light spectrum and the backscattered light spectrum are divided by the source spectrum, two absorption spectra (one for transmitted, one for backscattered) are obtained. The absorption spectrum of the transmitted light is preferably used in the hereinafter-described analysis if its count rate is sufficient. Otherwise, the backscattered absorption spectrum (or both) may be used.

Because different materials have different absorption characteristics, it becomes possible to make a determination as to what materials comprise the fluid sample, provided, of course, that the spectra of the materials which might be in the fluid sample are known. Towards that end, the spectra of water, gas, and a plurality of different oils are found in accord with techniques well known in the art. Examples of such spectra are seen Figure 5a, water has absorption peaks at about 1.5 and 1.9 microns. As seen in Figure 5b, crude oil has an absorption peak at 1.7 microns. The particular crude oil shown in Figure 5b has increasing absorption for wavelengths less than 1.6 microns. Many crude oils have a similar feature, but the onset is often at shorter wavelengths. Refined oils such as kerosene shown in Figure 5c, are generally transparent between .7 and 1.1 microns. However, like crude oil, they typically have an absorption peak at 1.7 microns and other features which appear in crude oil at 1.2 and 1.4 microns.

Using the absorption spectra of water, gas, crude and refined oils, and drilling fluids (muds), a least squares analysis such as is described generally in Bevington, Philip R., Data Reduction and Error Analysis for the Physical Sciences, McGraw-Hill Book Co., New York (1969), may be used to determine the components of the fluid sample. Or, if desired, a principle component analysis such as is described generally in Williams, P.C., et al., J. Agricultural Food Chemistry, Vol. 33, pg. 239 (1985), could be used in a similar manner to deter-

mine the components of the fluid sample. The analysis is preferably conducted in a processing mess such as a computer which is located uphole in the electronics and processing circuitry 18.

With regard to the fitting technique used to determine the fluid components, not only may a single spectrum for water, gas, oils, etc. be used in the data base, but, if desired, both transmission and backscattered absorption spectra may be utilized for each. Moreover, it will be appreciated that the spectra of the various components may vary with temperature and pressure. Thus, not only should the spectra of water, gas, and a plurality of oils be used as reference spectra, but a plurality of different spectra for each different material at different pressures and temperatures (and if desired for transmission and backscatter) should be available for an accurate determination of the fluid components to be made.

Those skilled in the art will appreciate that natural gas has a similar spectral shape to certain oils. On the other hand, because gas has a low density, only a small fraction of the light having a wavelength range of .3 to 2.5 will be absorbed by the sample. Thus, in accord with another aspect of the invention, the spectrum obtained by fiber optic bundle 34c may be compared to the spectrum obtained by fiber optic bundle 34d, to give a first indication of the percent gas contained in the sample. Having such an indication permits a more complete fitting of the different spectra even if the gas spectrum is very similar to one or more of the oil spectra.

Also, in accord with another aspect of the invention, the visible light and/or near-ultraviolet spectrum, preferably from .3 to 1 micron in wavelength, may be used to obtain indications of large molecules in a fluid such as porphyrins, asphaltenes, large aromatics, and resins. While these large molecules are present in low concentrations, they are easy to observe due to the absorption by their electronic transitions. Because the concentration and kind of large molecules in mud filtrates and formation fluids usually differ, a correlation of the large molecule .3 to 1 micron spectra provides an indication as to whether the fluid sample flowing through the optical cell 37 is changing over time. Since the first fluid to enter the cell 37 typically is the drilling fluid, the sample may be expelled rather than stored in chambers 22 or 23. Likewise, after the large molecule spectra indicate a change in fluid type (even though the NIR spectra for the oil and/or water in the fluid remain substantially the same as might be the case with an oil based mud filtrate and formation oil), the sample may be identified as a formation fluid sample, and the sample may be forwarded from the fluid analysis module 25 to the storage chambers for delivery uphole.

In connection with yet another aspect of the invention, the obtained spectra as well as the determination of the presence of gas may be used to control the pressure of the flow line so as to obtain a more representative sample of the formation fluid. In the situation where the formation fluid is comprised of both heavy and light hydrocarbons, bubbles of the lighter hydrocarbon can evolve out of the fluid, or the heavier hydrocarbons can condense out of the fluid. When the pressure of the fluid is below either the bubble point pressure or the dew point pressure (depending on the case) the fluid emerges from the formation in both the liquid and vapor phase. Since the less viscous vapor phase flows more freely than the liquid phase, the obtained sample includes more light hydrocarbons than is representative of the formation fluid. By changing the pressure in the flow line which is accomplished by standard techniques, the bubble point or dew point may be found as both of these effects will result in a decrease of transmitted light and an increase of backscattered light. The monitoring of transmission and reflection is best accomplished at a wavelength at which absorption is weak and at which the sample is relatively transparent. Once the bubble point or dew point pressure is found, the pressure of the flow line (sampling pressure) is increased above the relevant point by e.g., controlling the rate at which fluid flows through the sampling apparatus and/or locating the sampling apparatus at an appropriate depth in the well.

Turning to Figure 6, an alternative embodiment 125 of the fluid analysis module 25 of the borehole apparatus 10 is seen. Basically, the fluid module components are the same as the preferred embodiment, except that instead of using optical fiber bundles, directing and focussing mirrors are used. In accord with the embodiment of Figure 6, the source 130 is identical to that used in the preferred embodiment. The source is partially reflected by beam splitting mirror 135a to a reference detector 131 where a determination of the source spectrum downhole may be had. The non-reflected light is forwarded to collimating mirror 135b. The collimated light is then forwarded via directing mirrors 135c and 135d towards the optical cell 138 which is comprised of a high pressure stainless steel chamber with a fluid sample tube 132 passing therethrough, and with an optical path 139 perpendicular to and interrupted by the tube 132 also passing therethrough. In optical cell 138, the fluid sample tube 132 has sapphire windows 140. Light passing from mirror 135d into optical path 139, and either transmitted or scattered through the fluid sample exits the optical cell 138 and is directed by mirror 135e to the spectrometer (spectrograph) 136 which is preferably similar to the aforedescribed spectro-

graph 36 of Figure 4. If desired, the spectrometer 136 may be used in lieu of the reference detector 131, provided suitable optical means (not shown) are used to transport light directly from the source to the spectrometer and other means (multiplexing) are used to select either the light from the source or the light from the optical cell. Additionally, backscattered light may be analyzed by the spectrometer if mirror 135c is replaced by a suitable beam splitter and additional suitable optical means (not shown) are used to transport the backscattered light to the spectrometer. With such additional optical means, it will be appreciated that the embodiment of Figure 6 becomes the functional equivalent of the embodiment of Figure 4, with fiber optics being replaced by reflective optics.

Turning to Figure 7, a fluid analysis module 225 of a production logging tool is seen. The theoretical basis for the fluid analysis module 225 is identical to the fluid analysis modules of Figures 3 and 6. However, instead of providing a fluid admitting assembly for obtaining fluid samples from the formation and chambers for storage of the obtained samples, fluid is already flowing through the tool 200. As in the previously discussed modules, the fluid analysis module 225 uses a quartz halogen lamp as a light source 230. As in the embodiment of Figure 6, a beam splitter mirror 235a is used to permit a reference detector 231 to sense and determine the spectrum of the source, and to send on the beam towards the fluid to be sampled. The beam is directed by collimating mirror 235b through a sapphire window 237 and then through a sapphire rods 241a having reflective surface or minor 235c contained therein. The beam is then directed through a fluid sample which is obtained by mixing fluid by spinner 265, and having some of the fluid passing through an opening of approximately five millimeters between the sapphire rods 241a and 241b (the opening comprising a "testing region". The fluid then exits the fluid analysis module 225 through ports 270a and 270b in the wall of tool 200. The light which is transmitted or scattered through the fluid is then transmitted through sapphire rod 241b which includes a reflective surface or mirror 235d, out through sapphire window 237 and directly to spectrometer 236. Again, spectrometer 236 is preferably a spectrograph as shown in Figure 3, and the spectrometer may be used as the reference detector. Also, as was described with reference to Figure 6, the backscattered light may also be directed to the spectrometer by a suitable arrangement of reflective optics.

In operation, the borehole logging tool 10 shown in Figures 2 and 3 is placed downhole via extended cable 15. At a desired location, electronic section 18 provides signals to electronic section 16 which causes anchoring member 21 and admitting assembly 20 to extend into contact with the borehole walls. Upon a second signal from electronic section 16, and in accord with known tools in the art, formation fluid is obtained by the admitting assembly 20 and forwarded into the sample tube 32 of the fluid analysis module 25. Concurrently, light emitted by an optical source 30 is carried via optical fibers 34 to optical cell 37 where it is transmitted through, scattered by, and absorbed by the fluid sample. Forward scattered light, and light transmitted through the sample are forwarded to the spectrograph 36 where the transmitted, forward scattered spectrum is separated into its component wavelengths. Also, preferably, backscattered light and a spectral sample of the optical source are forwarded to the spectrograph 36 via a fiber optical bundle for division into its wavelength components. Each spectrum is sampled in order (the source spectrum not necessarily being sampled as often). Then, using detector array 38 and electronic section 16, the different spectral information is forwarded uphole to electronic and processing section 18 for analysis. Also, if desired, fluid temperature and pressure information may also be forwarded uphole. Preferably, using a least squares fit, the processor in processing section 18 fits the obtained spectra (with wavelengths from .3 to 2.5 microns) to a plurality of temperature-and pressure-specific absorption spectra for oils, water, and gas which are stored in a data base accessible to the processor. As a result of the fitting process, a determination is made of the components which comprise the fluid sample. A log of such a determination over borehole depth can then be made.

As indicated above, if both backscatter and forward scatter and transmission information is obtained, a first indication of the presence of gas may be had. This first indication may then be used to help in the fitting process. Also, if desired, using the spectrum from approximately .3 microns to 1 micron, a determination of whether a change has occurred in the types and/or quantities of large molecules may be had by using a correlation technique. The determination of whether a fluid change has occurred may then be used by the processor 18 via electronic section 16, to cause the fluid sample to be expelled into the borehole or to be forwarded into holding chambers 22 or 23 for further uphole analysis.

Figure 8 is a schematic diagram of the optic cell of Figure 3. A fiber optic bundle 324A carries light from a light source, such as the source 30 of Figure 3, to a first window section 40A. The window section 40A comprises a portion of a sample tube 32 through which a fluid sample flows. The sample tube 32 also comprises a chamber for containing the fluid sample. The fluid sample is illustrated by

varying shades of grey in the sample tube 32.

Light carried by the fiber optic bundle 324A passes through the fluid sample in the sample tube 32 and is scattered by the fluid sample. The amount of light that is scattered by the fluid sample depends on the composition of the fluid sample. In a multiphase flow stream, such as formation fluid, the composition of the flow stream varies greatly because the composition of the flow stream is not at all uniform. For example, the flow stream will include, among other things, bubbles of gas, particles of sand, and globules of oil. Gas, illustrated by the light area 41A, flowing in the sample tube 32 scatters the light to a small degree as the gas flows by the window section 40A. Because the light is scattered to a small degree, a relatively high intensity light signal passes through the fluid sample and reaches a second window section 40B. Conversely, sand, illustrated by the dark area 41B, flowing in the sample tube 32 scatters the light from the fiber optic bundle 324A to a greater degree as the sand flows by the window sections 40A. Because the light is scattered to a greater degree, a lower intensity light signal reaches the window section 40B. A second fiber optic bundle 324B carries the resulting light signal from the window section 40B to the spectograph 36 of Figure 3 for analysis. Because the degree of scattering can change abruptly as different phases of fluid pass by the window sections 40A and 40B, great swings occur in the intensity of the light signs that passes through the fluid sample. The spectograph, which receives such signals, must be designed to accommodate these swings in order to process the information that the light signal represents.

Accordingly, the inventors have developed a technique and device for minimizing the effects of such large signal swings. The technique and device concerns the measurement of indirect transmitted or forward scattered light instead of direct transmitted light. Measuring indirect transmitted light results in a light signal having a more consistent amplitude that is less affected by variations in flow patterns and phase changes within the sample tube 32, for example. In creating a light signal having a more constant amplitude, a significant reduction in signal swing occurs.

Figures 8A and 9 show two preferred embodiments of the invention that compensate for the effects of signal swing by modifying the optical path of light from the input fiber optic bundle 324A and the window section 40A through the fluid sample to the window section 40B and the output fiber optic bundle 324B. These embodiments alter the optical path of light through the fluid sample to allow the detection and measurement of substantially indirect transmitted light.

Figure 8A shows the second window section 40B of Figure 8 having a diffuser 41. The diffuser 41 is a distinct element that is attached to or, preferably, is formed directly on the surface of the window section 40B. The diffuser 41 is formed by scoring or etching the surface of the window section 40B. The diffuser on the window section 40B increases the collection angle of light that passes through the fluid.

Light from the fiber optic bundle 324A enters the window section 40A and exits as a broadening beam 42 of light that passes into fluid contained in the sample tube 32. One light ray 43 of the beam 42 hits a sand particle 44 or oil droplet in the fluid, for example. Many sand particles are present in the fluid, but only one is shown in Figure 8A for simplicity. The sand particle 44 in the fluid scatters the light in many directions. Forward scattered light 45 is transmitted toward the far side of the sample tube 32. The diffuser 41 collects the light that scatters from the sand particle 44 and reflects a substantial amount of the collected light 46 toward the output fiber optic bundle 324B. The diffuser 41 reduces the intensity of light from the fiber optic bundle 324A that is directly transmitted through the fluid sample in the sample tube 32 to the fiber optic bundle 324B, for instance. However, the diffuser 41 changes the solid angle of emission of the scattered ray from the sand particle thereby providing an effective wider angle of light acceptance 47 for the output fiber optic bundle 324B. Without the diffuser 41, a narrow angle of light acceptance 47, which is determined by the numerical aperture of the output fiber optic bundle 324B, would collect less of the light that was scattered by the sand particle in the fluid.

For example, in the case of a window section 40B having no diffuser, a ray of light 45a would be scattered by the sand particle 44 outside the angle of acceptance 47. Thus, the scattered light ray 45a would never reach the output fiber optic bundle 324B. However, according to this invention, the light ray 45a is scattered by the sand particle 44 to the diffuser 41, which again scatters or redirects the light ray 45a within the angle of acceptance 46 of the output fiber optic bundle 324B.

The intensity of light that passes through the diffuser 41 and reaches the fiber optic bundle 324B is substantially less than the intensity of light that would be directly transmitted from a light input through a chamber and to a light output, for example. This light of less intensity produces a weaker signal to the spectograph. However, this weaker signal is accepted as a tradeoff for signal stability.

Instead of a diffuser, a collecting lens can decollimate the forward scattered light onto the output fiber optic bundle 324B. A diffuser can also be formed on the surface of the first window sec-

tion 40A alone, or in addition to the window section 40B to broaden the angle of light transmitted from the window section 40A and broaden the angle of light acceptance of the output optic fiber bundle 324B. The diffuser 41 can also be formed on the end of either fiber optic bundle 324A or 324B or on the prisms of Figure 3.

Figure 9 shows an embodiment in which the output fiber optic bundle 324B is misaligned relative to the input fiber optic bundle 324A to modify the optic path of light transmitted through the sample fluid in the sample tube 32. These bundles are misaligned in that the longitudinal axis of the bundles are not collinear or parallel. In a preferred embodiment, the fiber optic bundle 324B connects to the window section 40B through a prism and parallels the fiber optic bundle 324A, as Figure 3 illustrates. Figure 9 shows the fiber optic bundle 324B without a prism for simplicity.

The misalignment of input and output bundles reduces the amount of light from the fiber optic bundle 324A that is directly transmitted through the fluid sample in the sample tube 32 to the fiber optic bundle 324B, because the directly transmitted light, illustrated by a thick arrow, misses the output fiber optic bundle 324B. Only indirect light, illustrated by a thin arrow, reaches the output fiber optic bundle 324B. Compared to an optic cell system having parallel and offset input and output fiber optic bundles, the system of Figure 9 reduces the amount of indirect light entering the fiber optic bundle 324B when the fluid between the window sections 40A and 40B comprises a gas bubble, but increases the amount of indirect light entering that bundle when the fluid comprises a particle of sand, for instance. This allows the spectograph to receive a relatively constant signal which is, therefore, not easily affected by flow variation within the sample tube 32. Thus, measuring the forward scattered, indirect transmitted light results in a large reduction in signal swing, and a reduction in overall signal level.

A scattered light fiber optic bundle 324C transmits any backscattered light, such as that which reflects off of sand particles in the sample tube 32, to the spectograph 36 of Figure 3 for reflection spectroscopy. The spectograph uses the signals of the bundle 324C, along with the signals of the output fiber optic bundle 324B in analyzing the formation fluid in the sample tube 32.

Claims

1. Apparatus for analyzing the composition of a formation fluid comprising at least one of oil, water and gas, and including a light source (30) for emitting infrared radiation, means (34b) for directing the radiation from the light source (30) to a chamber (32) containing the formation fluid to be analyzed, a detector (36) for detecting radiation transmitted through the fluid in the chamber and means (18) for analyzing the composition of the fluid on the basis of the transmitted radiation; characterized in that:

   a) the apparatus comprises borehole apparatus (10) containing the light source (30), the chamber (32), the means (34b) for directing the radiation from the light source to the chamber (32) and the detector (36), which can be positioned adjacent the formation (14) from which the fluid is to be obtained;

   b) means (20) are provided in said borehole apparatus (10) for admitting fluid from the formation (14) into the chamber (32); and

   c) the means for analyzing the fluid includes means (34a, 36) for obtaining the spectrum of the light source (30) and processing means including a database of near infrared absorption spectral information of at least two of oil, water and gas, said processing means determining the composition of the fluid using the transmitted spectra, the light source spectrum and the data in the database.

2. Apparatus as claimed in claim 1, wherein means (34c, 34d) are provided for receiving light from the chamber (32) and means (40) are connected between the means (34b) for directing the radiation from the light source (30) to the chamber (32) and the means (34c, 34d) for receiving light from the chamber (32) for modifying the optical path of the light such that the light received by the means (34c, 34d) comprises light that passes indirectly through the fluid in the chamber (32).

3. Apparatus as claimed in claim 2, wherein the means (40) for modifying the optical path of the radiation comprises a diffuser (41).

4. Apparatus as claimed in claim 2 or 3, wherein the means (40) for modifying the optical path of the radiation comprise first and second windows (40A, 40B) formed from a material that is substantially transparent to the radiation and having an irregular surface.

5. Apparatus as claimed in claim 4, wherein the irregular surfaces of the first and second windows (40A, 40B) are scored.

6. Apparatus as claimed in claim 4, wherein the irregular surfaces of the first and second windows (40A, 40B) are etched.

7. Apparatus as claimed in any of claims 2 - 6, wherein the means (40) for modifying the optical path of the light comprises connecting means which misalign the means (34b) for directing the radiation from the light source (30) to the chamber (32) and the means (34c, 34d) for receiving light from the chamber (32).

8. Apparatus as claimed in claim 7, wherein the means for directing radiation to and from the chamber comprise misaligned optical fibres.

9. Apparatus as claimed in any preceding claim, wherein the means (20) for admitting fluid from the formation (14) into the chamber (32) is selectively extendible so as to isolate a portion of the borehole wall (12) and establish fluid communication with the formation (14).

10. Apparatus as claimed in any preceding claim, wherein the borehole tool (10) also includes an extendible tool anchoring member (21).

11. Apparatus as claimed in any preceding claim, wherein one or more fluid collecting chambers (22, 23) are provided in the downhole tool (10) and the means (20) for admitting fluid, the chamber (32) and the fluid collecting chambers (22, 23) are arranged such that formation fluid passes from the means (20), through the chamber (32) and into the fluid collecting chambers (22, 23).

12. A method for analyzing the composition of a formation fluid comprising at least one of oil, water and gas, and including the steps of illuminating a sample of the fluid in a chamber (32) with a light source (30) for emitting near infrared radiation, detecting the spectrum of radiation transmitted through the fluid in the chamber and analyzing the composition of the fluid on the basis of the transmitted radiation; characterized in that:

a) the steps of illuminating the sample and detecting radiation transmitted therethrough are performed in a borehole apparatus (10) containing the light source (30), the chamber (32) , means (34b) for directing the radiation from the light source to the chamber (32) and a detector (36), the borehole apparatus (10) being positioned adjacent the formation (14) from which the fluid is to be obtained;

b) fluid is admitted from the formation (14) into the chamber (32) via means (20) provided in said borehole apparatus (10); and

c) the step of analyzing the fluid includes obtaining the spectrum of the light source (30) and determining the composition of the fluid with processing means using the transmitted spectra, the light source spectrum and the data from a database of near infrared absorption spectral information of at least two of oil, water and gas, in the processing means.

13. A method as claimed in claim 12, comprising modifying the optical path of the illuminating radiation such that the detected radiation comprises radiation that passes indirectly through the fluid in the chamber (32).

14. A method as claimed in claim 13, wherein the step of modifying the optical path comprises using misaligned optical fibres for illuminating the sample and detecting radiation.

15. A method as claimed in any of claims 12 - 14, comprising extending the means (20) for admitting fluid from the formation (14) into the chamber (32) so as to isolate a portion of the borehole wall (12) and establish fluid communication with the formation (14).

16. A method as claimed in any of claims 12 - 15, comprising anchoring the borehole tool (10) in the borehole by means of an extendible tool anchoring member (21).

17. A method as claimed in any of claims 12 - 16, wherein formation fluid passes from the means (20), through the chamber (32) and into fluid collecting chambers (22, 23) provided in the borehole tool (10).

Patentansprüche

1. Vorrichtung für das Analysieren der Zusammensetzung eines Formationsfluids, umfassend zumindest eines von Öl, Wasser und Gas einschließlich einer Lichtquelle (30) für das Emittieren von Infrarotstrahlung, Mitteln (34b) für das Richten der Strahlung von der Lichtquelle (30) auf eine Kammer (32), die das zu analysierende Formationsfluid enthalt, mit einem Detektor (36) für das Erfassen von Strahlung, die durch das Fluid in der Kammer ausgesandt worden ist, und mit Mitteln (18) für das Analysieren der Zusammensetzung des Fluids auf der Basis der übertragenen Strahlung;

dadurch gekennzeichnet, daß:

a) die Vorrichtung eine Bohrlochsonde (10) umfaßt, welche die Lichtquelle (30), die Kammer (32), die Mittel (34b) für das Richten der Strahlung von der Lichtquelle auf

die Kammer (32) und den Detektor (36) umfaßt, der nahe der Formation (14), aus der das Fluid zu gewinnen ist, positioniert ist;

b) Mittel (20) vorgesehen sind in der Bohrlochsonde (10) für das Einlassen von Fluid aus der Formation (14) in die Kammer (32); und

c) die Mittel für das Analysieren des Fluids Mittel (34a, 36) umfassen für das Gewinnen des Spektrums der Lichtquelle (30), und Verarbeitungsmittel umfaßt einschließlich einer Datenbasis der nahen Infrarot-Absorptionsspektralinformation von mindestens zwei von Öl, Wasser und Gas, welche Verarbeitungsmittel die Zusammensetzung des Fluids bestimmen unter Verwendung der übertragenen Spektren, des Lichtquellenspektrums und der Daten in der Datenbasis.

2. Vorrichtung nach Anspruch 1, bei der Mittel (34c, 34d) vorgesehen sind für das Empfangen von Licht aus der Kammer (32) und Mittel (40) angeschlossen sind zwischen den Mitteln (34b) für das Richten der Strahlung von der Lichtquelle (30) auf die Kammer (32) und den Mitteln (34c, 34d) für das Empfangen von Licht aus der Kammer (32) für die Modifikation des optischen Pfades des Lichtes derart, daß das von den Mitteln (34c, 34d) empfangene Licht Licht umfaßt, das indirekt durch das Fluid in der Kammer (32) verläuft.

3. Vorrichtung nach Anspruch 2, bei der die Mittel (40) für das Modifizieren des optischen Pfades der Strahlung einen Diffuser (41) umfassen.

4. Vorrichtung nach Anspruch 2 oder 3, bei der die Mittel (40) für das Modifizieren des optischen Pfades der Strahlung erste und zweite Fenster (40A, 40B) umfassen, gebildet aus einem Material, das im wesentlichen transparent für die Strahlung ist und eine unregelmäßige Oberfläche aufweist.

5. Vorrichtung nach Anspruch 4, bei der die unregelmäßigen Oberflächen des ersten und des zweiten Fensters (40A, 40B) gerillt sind.

6. Vorrichtung nach Anspruch 4, bei der die unregelmäßigen Oberflächen des ersten und des zweiten Fensters (40A, 40B) geätzt sind.

7. Vorrichtung nach einem der Ansprüche 2 - 6, bei der die Mittel (40) für das Modifizieren des optischen Pfades des Lichtes Verbindungsmittel umfassen, die die Mittel (34b) für das Richten der Strahlung von der Lichtquelle (30) auf die Kammer (32) und die Mittel (34c, 34d) für das Empfangen von Licht von der Kammer (32) fehlausfluchten.

8. Vorrichtung nach Anspruch 7, bei der die Mittel für das Richten der Strahlung auf und von der Kammer fehlausgefluchtete optische Fasern umfassen.

9. Vorrichtung nach einem der vorangehenden Ansprüche, bei der die Mittel (20) für das Einlassen von Fluid aus der Formation (14) in die Kammer (32) selektiv ausfahrbar sind, um so einen Abschnitt der Bohrlochwandung (12) zu isolieren und die Fluidkommunikation mit der Formation (14) herzustellen.

10. Vorrichtung nach einem der vorangehenden Ansprüche, bei der die Bohrlochsonde (10) auch ein ausfahrbares Sondenverankerungsglied (21) umfaßt.

11. Vorrichtung nach einem der vorangehenden Ansprüche, bei der eine oder mehrere Fluidsammelkammern (22, 23) in der untertägigen Sonde (10) vorgesehen sind und die Mittel (20) für das Einlassen von Fluid, die Kammer (32) und die Fluidsammelkammern (22, 23) derart angeordnet sind, daß das Formationsfluid von den Mitteln (20) durch die Kammer (32) in die Fluidsammelkammern (22, 23) fließt.

12. Ein Verfahren für das Analysieren der Zusammensetzung eines Formationsfluids, umfassend mindestens eines von Öl, Wasser und Gas, und umfassend den Schritt der Beleuchtung einer Fluidprobe in einer Kammer (32) mit einer Lichtquelle (30) für das Emittieren von naher Infrarotstrahlung, Erfassen des Spektrums der Strahlung, die durch das Fluid in der Kammer verläuft, und Analysieren der Zusammensetzung des Fluids auf der Basis der übertragenen Strahlung;

dadurch gekennzeichnet, daß:

a) die Schritte des Bestrahlens der Probe und der Erfassung der durch sie verlaufenden Strahlung in einer Bohrlochvorrichtung (10) ausgeführt werden, welche die Lichtquelle (30), die Kammer (32), Mittel (34b) für das Richten der Strahlung von der Lichtquelle auf die Kammer (32) und einen Detektor (36) enthält, welche Bohrlochvorrichtung (10) nahe der Formation (14), aus der das Fluid zu gewinnen ist, positioniert ist;

b) Fluid aus der Formation (14) in die Kammer (32) über Mittel (20) eingelassen wird, die in der Bohrlochvorrichtung (10) vorgese-

hen sind; und

c) der Schritt des Analysierens des Fluids das Gewinnen des Spektrums der Lichtquelle (30) umfaßt und das Bestimmen der Zusammensetzung des Fluids mittels Verarbeitungsmitteln unter Anwendung der übertragenen Spektren, des Lichtquellenspektrums und der Daten von einer Datenbasis von naher Infrarot-Absorptionsspektralinformation von mindestens zwei von Öl, Wasser und Gas in den Verarbeitungsmitteln.

13. Ein Verfahren nach Anspruch 12, umfassend das Modifizieren des optischen Pfades der beleuchtenden Strahlung derart, daß die erfaßte Strahlung Strahlung umfaßt, die indirekt durch das Fluid in der Kammer (32) verläuft.

14. Ein Verfahren nach Anspruch 13, bei dem der Schritt des Modifizierens des optischen Pfades die Verwendung von fehlausgefluchteten optischen Fasern umfaßt für das Beleuchten der Probe und die Erfassung der Strahlung.

15. Ein Verfahren nach einem der Ansprüche 12 - 14, umfassend Ausfahrmittel (20) für das Einlassen von Fluid aus der Formation (14) in die Kammer (32) derart, daß ein Abschnitt der Bohrlochwandung (12) isoliert wird und die Fluidkommunikation mit der Formation (14) hergestellt wird.

16. Ein Verfahren nach einem der Ansprüche 12 - 15, umfassend das Verankern der Bohrlochsonde (10) in dem Bohrloch mittels eines ausfahrbaren Sondenverankerungsgliedes (21).

17. Ein Verfahren nach einem der Ansprüche 12 - 16, bei dem Formationsfluid von den Mitteln (20) durch die Kammer (32) in Fluidsammelkammern (22, 23), die in der Bohrlochsonde (10) ausgebildet sind, fließt.

Revendications

1. Appareil pour analyser la composition d'un fluide de formation comprenant au moins un élément parmi du pétrole, de l'eau et du gaz, et comportant une source de lumière (30) pour émettre un rayonnement infrarouge, des moyens (34b) pour diriger le rayonnement de la source de lumière (30) vers une chambre (32) contenant le fluide de formation à analyser, un détecteur (36) pour détecter le rayonnement transmis à travers le fluide dans la chambre et des moyens (18) pour analyser la composition du fluide à partir du rayonnement transmis; caractérisé en ce que:

(a) l'appareil comprend un appareil (10) de puits contenant la source de lumière (30), la chambre (32), les moyens (34b) pour diriger le rayonnement de la source de lumière vers la chambre (32) et le détecteur (36), qui peut être positionné de façon adjacente à la formation (14) dont le fluide doit être obtenu;

(b) des moyens (20) sont prévus dans ledit appareil de puits (10) afin d'admettre un fluide de la formation (14) dans la chambre (32); et

(c) le moyen pour analyser le fluide comporte des moyens (34a, 36) pour obtenir le spectre de la source de lumière (30) et des moyens de traitement comprenant une base de données fournissant des informations spectrales d'absorption dans l'infrarouge proche d'au moins deux éléments parmi du pétrole, de l'eau et du gaz, lesdits moyens de traitement déterminant la composition du fluide par utilisation des spectres transmis, du spectre de la source lumineuse et des données de la base de données.

2. Appareil selon la revendication 1, dans lequel des moyens (34c, 34d) sont prévus pour recevoir de la lumière de la chambre (32), et des moyens (40) sont connectés entre les moyens (34b) pour diriger le rayonnement de la source de lumière (30) vers la chambre (32), et les moyens (34c, 34d) pour recevoir la lumière de la chambre (32) afin de modifier le trajet optique de la lumière de façon que la lumière reçue par les moyens (34c, 34d) comprenne de la lumière qui passe indirectement à travers le fluide dans la chambre (32).

3. Appareil selon la revendication 2, dans lequel les moyens (40) pour modifier le trajet optique du rayonnement comprennent un diffuseur (41).

4. Appareil selon la revendication 2 ou 3, dans lequel les moyens (40) pour modifier le trajet optique du rayonnement comprennent des première et seconde fenêtres (40A, 40B) formées d'un matériau qui est sensiblement transparent au rayonnement et ayant une surface irrégulière.

5. Appareil selon la revendication 4, dans lequel les surfaces irrégulières des première et seconde fenêtres (40A, 40B) sont striées.

6. Appareil selon la revendication 4, dans lequel les surfaces irrégulières des première et seconde fenêtres (40A, 40B) sont gravées.

7. Appareil selon l'une quelconque des revendications 2-6, dans lequel les moyens (40) pour modifier le trajet optique de la lumière comprennent des moyens de connexion qui modifient l'alignement des moyens (34b) pour diriger le rayonnement de la source de lumière (30) vers la chambre (32) et des moyens (34c, 34d) pour recevoir la lumière de la chambre (32).

8. Appareil selon la revendication 7, dans lequel les moyens pour diriger le rayonnement vers et en provenance de la chambre comprennent des fibres optiques non alignées.

9. Appareil selon l'une quelconque des revendications précédentes, dans lequel le moyen (20) pour admettre un fluide de la formation (14) dans la chambre (32) est sélectivement extensible de façon à isoler une partie de la paroi (12) du puits et établir une communication fluide avec la formation (14).

10. Appareil selon l'une quelconque des revendications précédentes, dans lequel l'outil de puits (10) comporte également un élément (21) d'ancrage d'outil extensible.

11. Appareil selon l'une quelconque des revendications précédentes, dans lequel une ou plusieurs chambres collectrices de fluide (22, 23) sont prévues dans l'outil (10) de puits et les moyens (20) pour admettre le fluide, la chambre (32) et les chambres collectrices de fluide (22, 23) sont disposés de façon que le fluide de formation passe des moyens (20), à travers la chambre (32), dans les chambres collectrices de fluide (22, 23).

12. Procédé pour analyser la composition d'un fluide de formation comprenant au moins un élément parmi du pétrole, de l'eau et du gaz et comportant les étapes consistant à éclairer un échantillon du fluide dans la chambre (32) avec une source de lumière (30) pour émettre un rayonnement dans l'infrarouge proche, à détecter le spectre du rayonnement transmis à travers le fluide dans la chambre et à analyser la composition du fluide à partir du rayonnement transmis; caractérisé en ce que:

a) les étapes d'éclairement de l'échantillon et de détection du rayonnement transmis à travers celui-ci sont effectuées dans un appareil de puits (10) contenant la source de lumière (30), la chambre (32), des moyens (34b) pour diriger le rayonnement de la source de lumière vers la chambre (32) et un détecteur (36), l'appareil de puits (10) étant positionné de façon adjacente à la formation (14) dont le fluide doit être obtenu;

b) un fluide est admis de la formation (14) dans la chambre (32) par l'intermédiaire de moyens (20) prévus dans ledit appareil de puits (10); et

c) l'étape d'analyse du fluide comprend l'obtention du spectre de la source de lumière (30) et la détermination de la composition du fluide par des moyens de traitement utilisant les spectres transmis, le spectre de la source de lumière et les données d'une base de données d'informations spectrales d'absorption dans l'infrarouge proche d'au moins deux éléments parmi du pétrole, de l'eau et du gaz, dans les moyens de traitement.

13. Procédé selon la revendication 12, comprenant la modification du trajet optique du rayonnement d'éclairement de façon que le rayonnement détecté comprenne un rayonnement qui passe indirectement à travers le fluide dans la chambre (32).

14. Procédé selon la revendication 13, dans lequel l'étape de modification du trajet optique comprend l'utilisation de fibres optiques non alignées pour éclairer l'échantillon et détecter le rayonnement.

15. Procédé selon l'une quelconque des revendications 12-14, comprenant l'extension des moyens (20) pour admettre un fluide de la formation (14) dans la chambre (32) de façon à isoler une partie de la paroi (12) du puits et établir une communication fluide avec la formation (14).

16. Procédé selon l'une quelconque des revendications 12-15, comprenant l'ancrage de l'outil de puits (10) dans le puits au moyen d'un élément (21) d'ancrage d'outil extensible.

17. Procédé selon l'une quelconque des revendications 12-16, dans lequel le fluide de formation passe des moyens (20), à travers la chambre (32), dans des chambres collectrices de fluide (22, 23) prévues dans l'outil de puits (10).

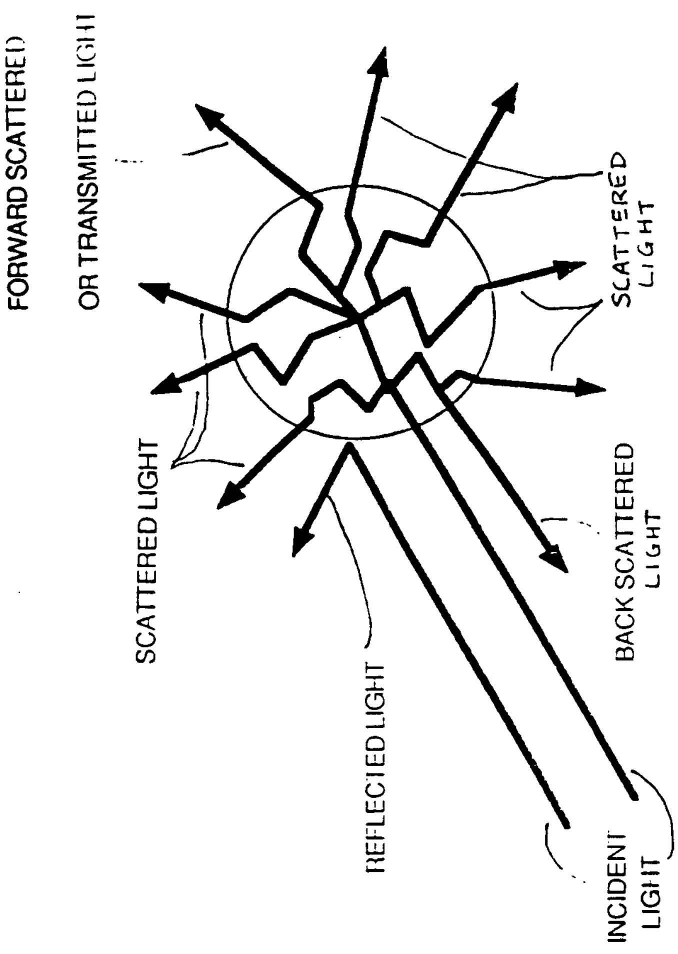

FORWARD SCATTERED
OR TRANSMITTED LIGHT
SCATTERED LIGHT
SCATTERED
LIGHT
REFLECTED LIGHT
BACK SCATTERED
LIGHT
INCIDENT
LIGHT

FIG. 1

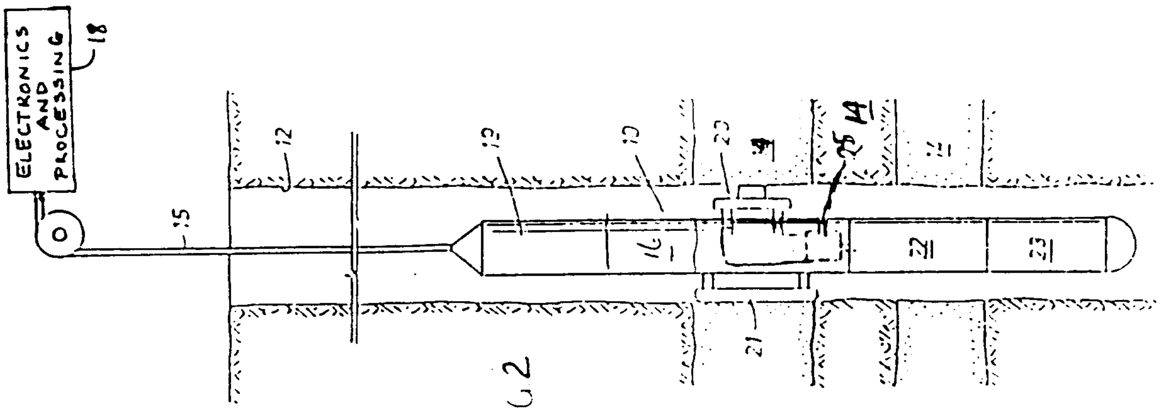

ELECTRONICS
AND
PROCESSING
18
15
12
10
16
22
23
21
25

FIG. 2

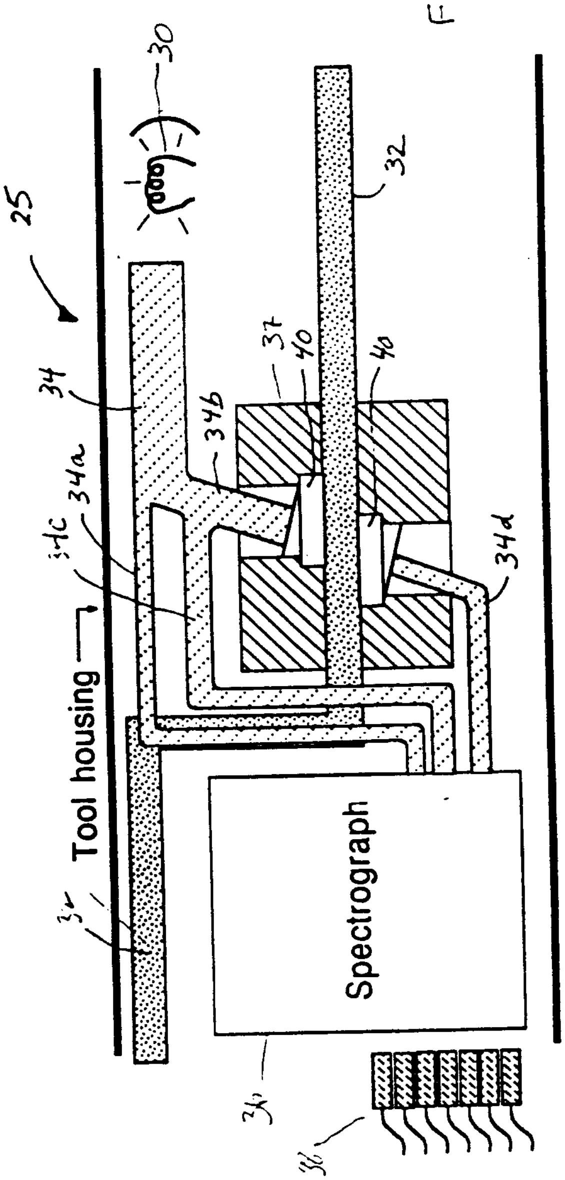

25
30
32
34
34a
34b
34c
34d
37
40
40
Tool housing
Spectrograph
36

FIG. 3

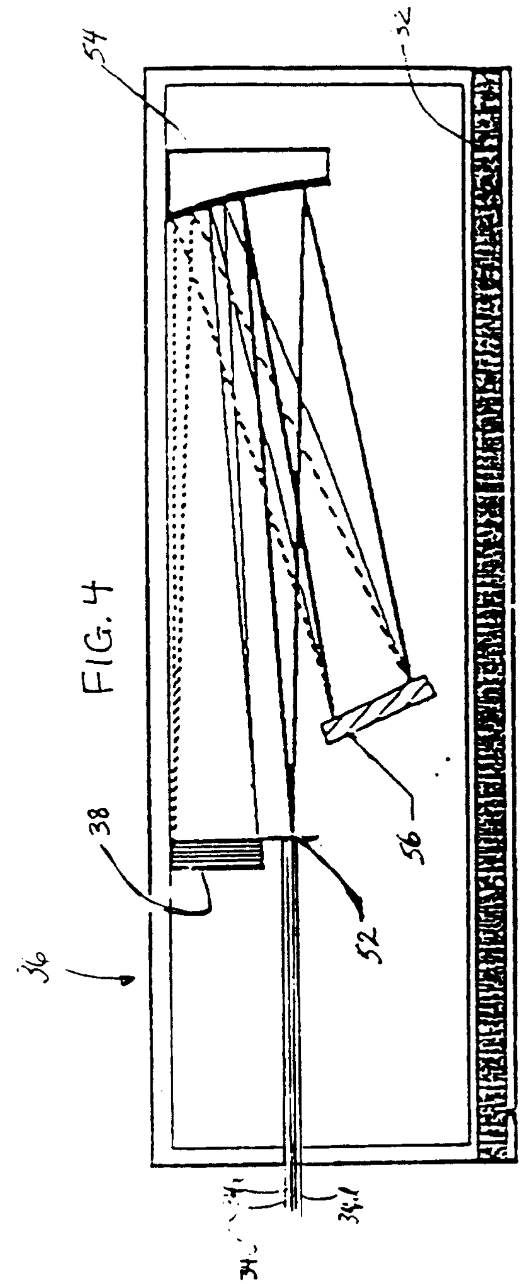

54
32
38
52
56
36

FIG. 4

FIG. 5a

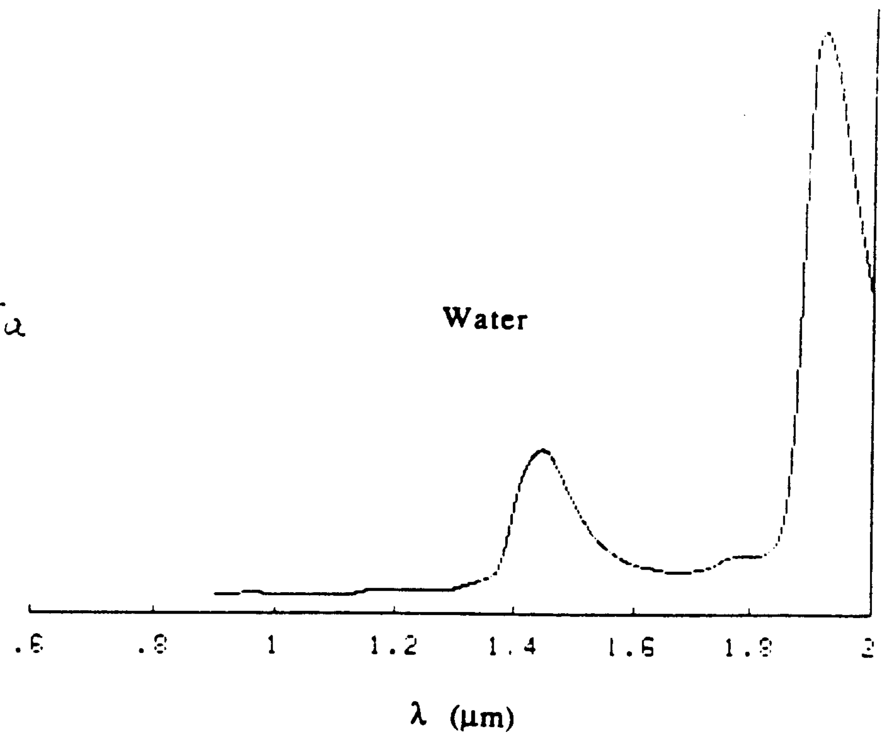


FIG. 5b

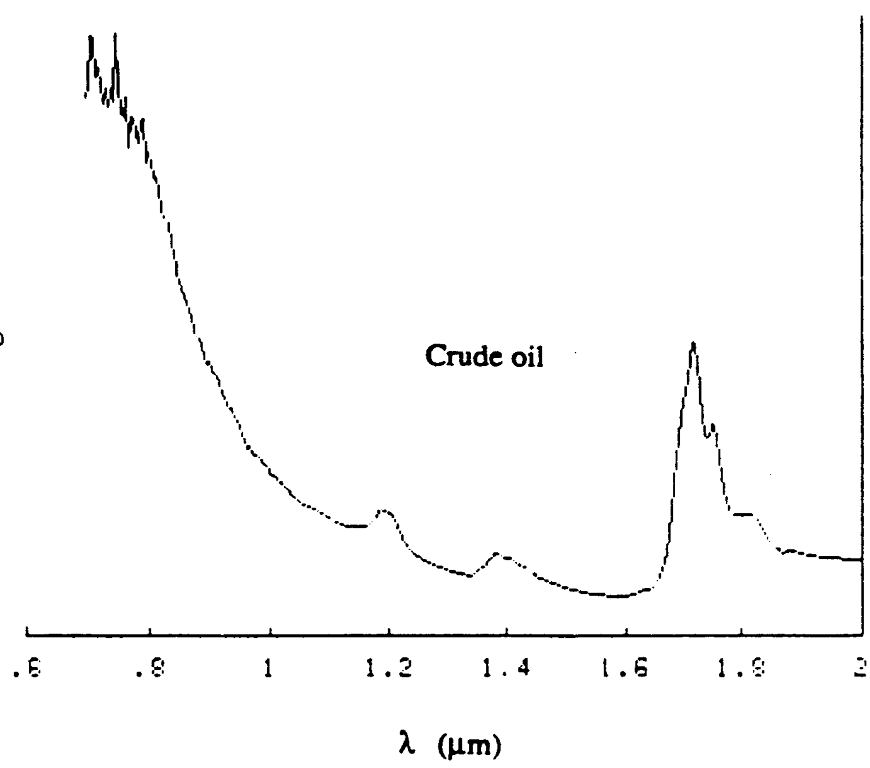


FIG. 5c

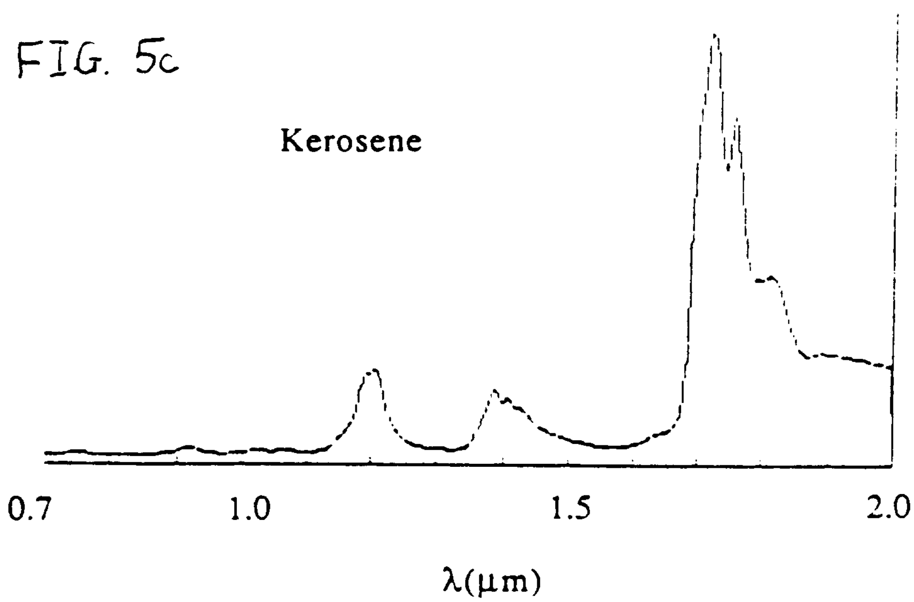


Figure 7.

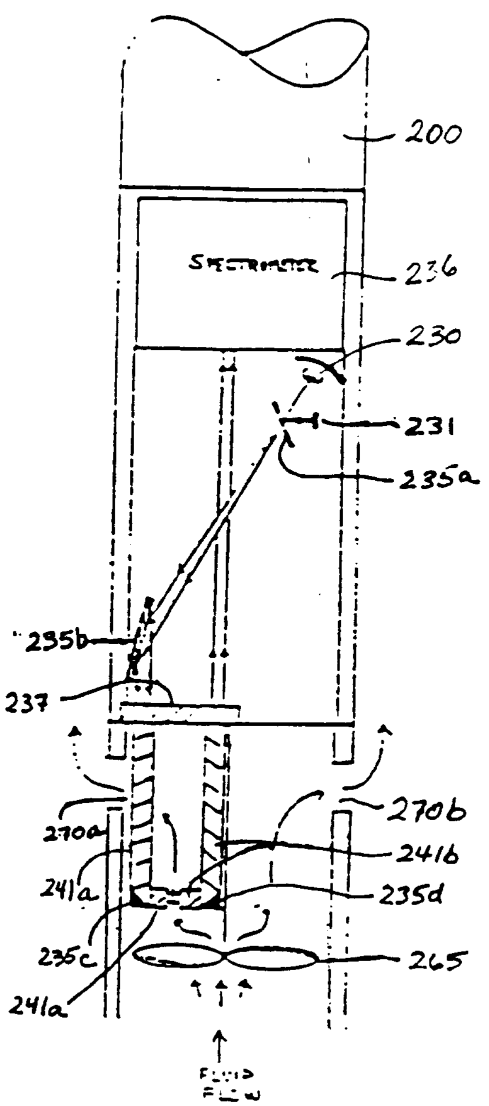
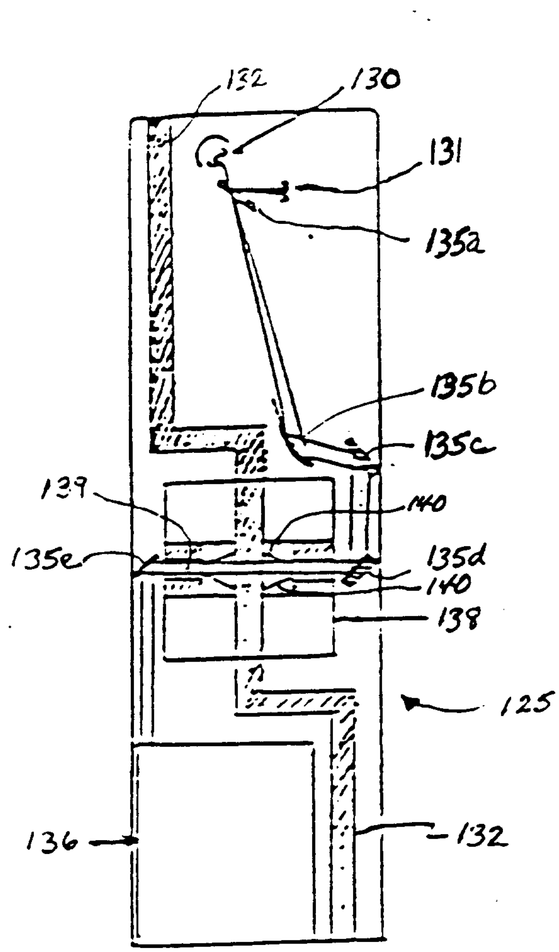


Figure 6.



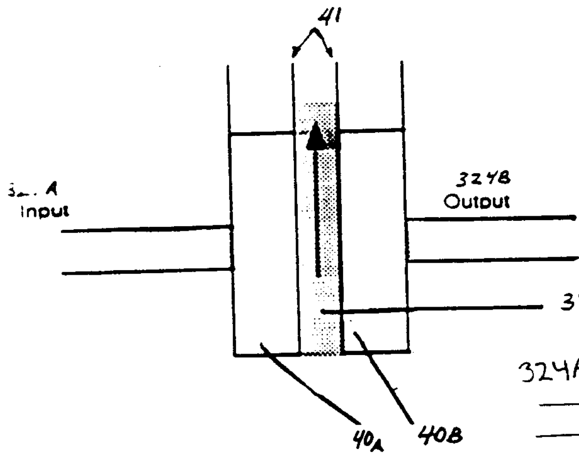


FIG 8

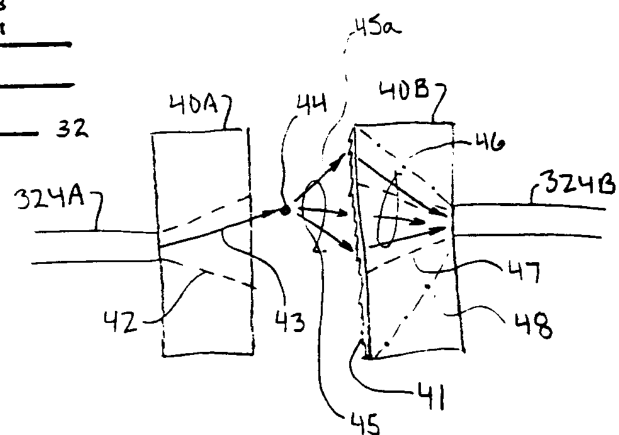


FIG 8A

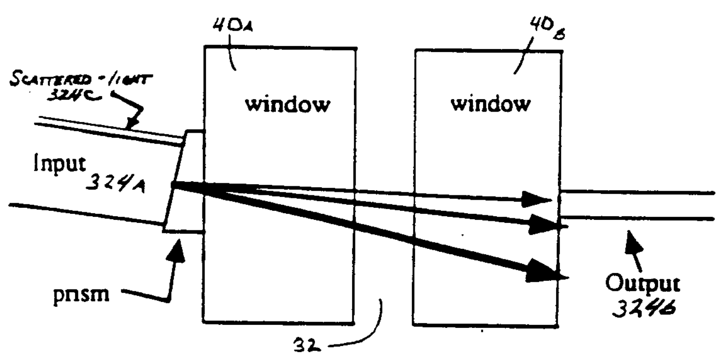


FIG 9